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The Air Force Global Weather Central Surface Temperature Model

by

Thomas J. Kopp, PhD

December 1995

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AIR FORCE GLOBAL WEATHER CENTRAL
106 Peacekeeper Drive
Offutt Air Force Base, Nebraska 68113-4039

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David P. Urbanski

DAVID P. URBANSKI, Lt Col, USAF
Chief, Systems Division

FOR THE COMMANDER

James S Perkins

JAMES S. PERKINS
AWS Scientific and Technical Information Program Manager
1 December 1995

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13. Abstract: Describes AFGWC's Surface Temperature Model (SFCTMP) mainframe computer program. Explains how it produces global temperature analyses and forecasts at and near the earth's surface. Explains the various processors used and the ties to other models, particularly the RTNEPH. Quality control and deficiencies are covered.

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PREFACE

The Air Force Global Weather Central Surface Temperature Model (SFCTMP) analyzes and forecasts global shelter and skin temperature. The output is primarily used by the Real-Time Nephanalysis (RTNEPH) to produce a global cloud analysis. The RTNEPH is then used by the AFGWC cloud forecast models. This technical note provides specific information on the SFCTMP, including a discussion of each processor, the algorithms, the ties to the other models, and the strengths and weaknesses of the model. It can also help those investigating the potential use of this model in their own applications.

For more information, please call the Cloud Models Team, Meteorological Models Section (SYSM), AFGWC at DSN 271-3533 or Commercial (402) 294-3533.

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INTRODUCTION

The Air Force Global Weather Central (AFGWC) Surface Temperature model (SFCTMP) produces global temperature analyses and forecasts at and near the earth's surface. It primarily supports the AFGWC Real-Time Nephanalysis (RTNEPH) model, but has other users. The RTNEPH cloud analysis model requires this data to make a cloud/no-cloud decision in its infrared (IR) thresholding algorithm. More information regarding RTNEPH can be found in AFGWC/TN—88/001, *The AFGWC Automated Real-Time Cloud Analysis Model*, and in Hamill et al., 1992.

SFCTMP was rewritten in 1990 as part of an overall effort to significantly improve the quality of cloud forecasting at AFGWC. The new SFCTMP has been operational since the spring of 1991. The operating philosophy is:

• Cloud analysis quality directly benefits from an improved surface temperature model.

• Cloud forecast models benefit from an improved cloud analysis.

Chapter 2

ANALYSIS GRID

SFCTMP runs separate analyses/forecasts for the northern and southern hemispheres. For each hemisphere, data is mapped onto a polar stereographic grid. This projection overlays a 512 x 512 array of points at "1/8th-mesh" resolution, which is 47.625 km (true at 60 degrees north). These points are referred to as gridpoints.

The array of gridpoints is organized into 64 boxes, called RTNEPH boxes, which are laid out in an 8 x 8 array (See Figures 2-1 and 2-2). Thus, each RTNEPH box comprises a 64 x 64 array of gridpoints. The RTNEPH model was the original driver for this grid usage.

For more information on either the 1/8th-mesh grid or the overlaid polar stereographic projection, refer to Hoke et al., 1981.

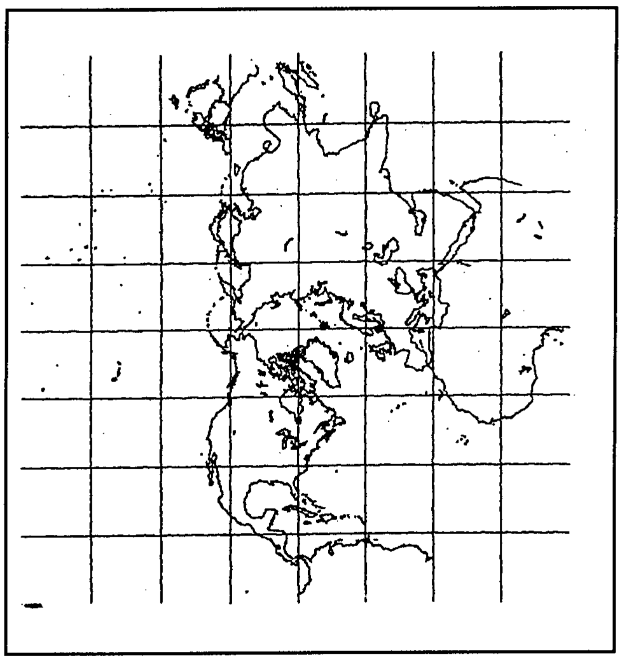

Figure 2-1. Northern hemisphere RTNEPH grid.

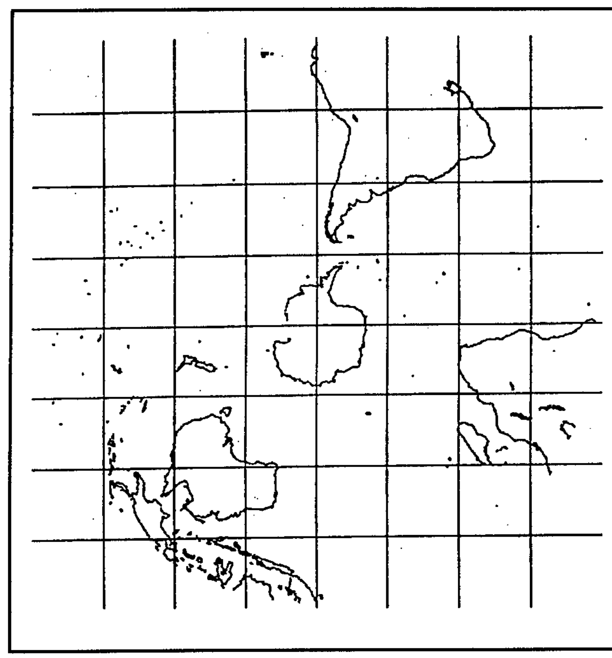

Figure 2-2. Southern hemisphere RTNEPH grid.

Chapter 3

SYSTEM OVERVIEW

3.1 General Contents. SFCTMP produces an analysis, 3-hour forecast, and a 4.5-hour forecast of "shelter" temperature (2 meters above the earth's surface) and skin (ground/atmosphere interface) temperature, at each gridpoint. These data are tailored to the needs of the RTNEPH, keeping the following specifics in mind:

• RTNEPH cloud analysis is performed on the 1/8th-mesh grid.

• RTNEPH has the capability to utilize both skin and shelter temperatures when determining a cloud/no-cloud threshold for its infrared channel algorithm.

• RTNEPH requires temperature forecasts valid up to 4.5 hours after the SFCTMP analysis valid time. This ensures its cloud analysis algorithm uses timely temperature fields.

SFCTMP runs every three hours at 00, 03, 06, 09, 12, 15, 18, and 21 UTC. Temperatures are stored in tenths of degrees Kelvin from 200.0 - 350.0 K.

NOTE: Descriptions here refer to the operational SFCTMP database. SFCTMP shelter temperatures are also archived. For more information on either the distribution or disposition of archived SFCTMP data, write or call:

OL-A, AFCCC
151 Patton Ave Rm 120
Asheville, NC 28801-5002
DSN 266-3100
Commercial (704) 271-4201

3.2 Functions. Figure 3.1 provides a broad illustration of control and data flow between the five major modules comprising SFCTMP. These modules are listed below:

• *HIRAS (High Resolution Analysis System) Data Processor.* Converts HIRAS 2.5 degree resolution low-level atmospheric temperature, wind, and relative humidity analyses to 1/8-mesh resolution for use in other SFCTMP modules.

• *Land Analysis Processor.* Produces the land surface temperature analysis.

• *Sea Surface Analysis Processor.* Produces the sea-surface temperature analysis and forecast (the latter by persistence).

• *Land Forecast Processor.* Produces the land surface temperature forecasts valid at 3 and 4.5 hours after analysis time.

• *Smoother.* Smooths all land forecast fields to reduce errors and ensures better interaction between RTNEPH and SFCTMP.

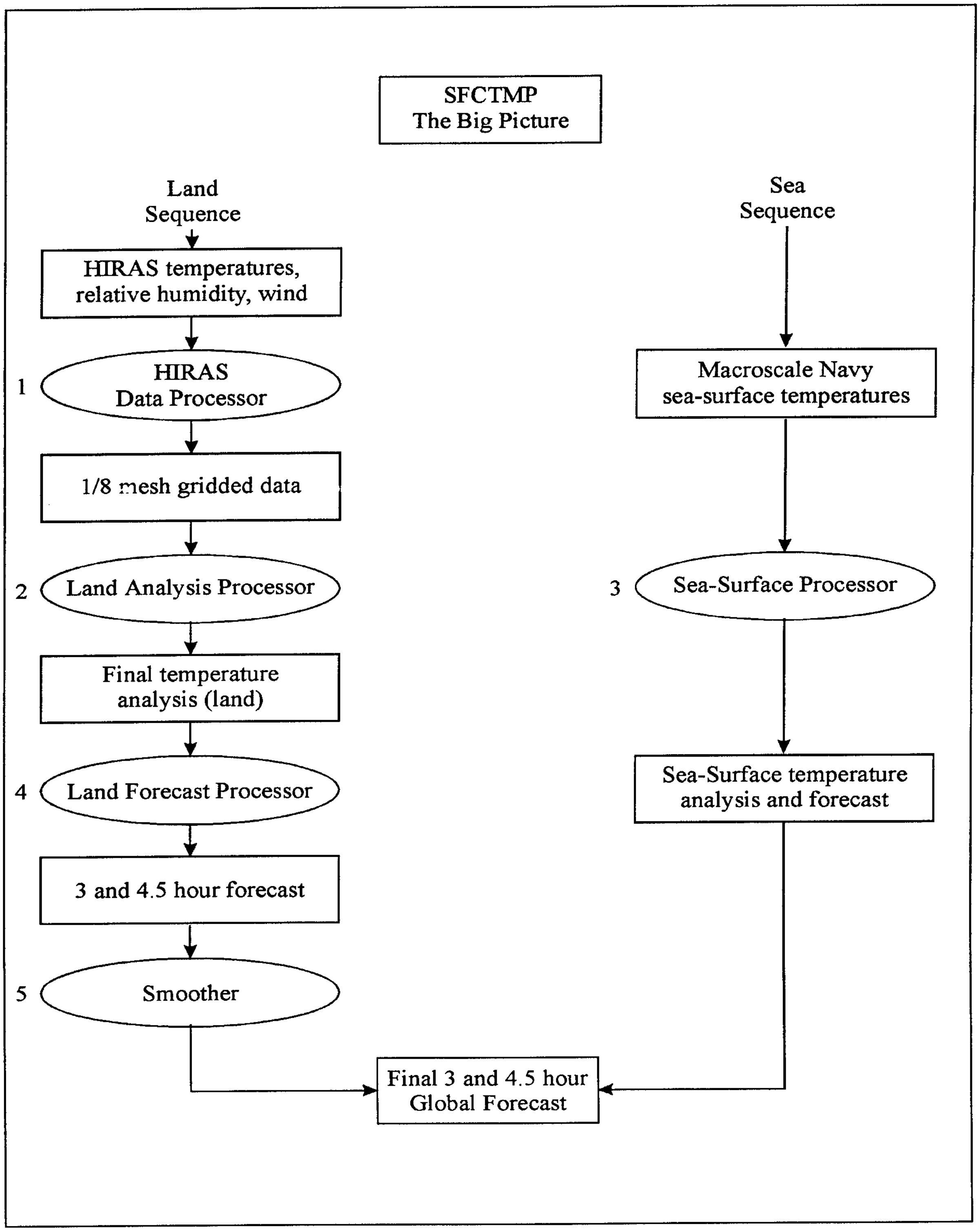

Figure 3-1.
Broad view of SFCTMP (numbers indicate execution sequence).

3.3 Model Interactions. In addition to conventional data, SFCTMP receives key input from other AFGWC models are shown in Figure 3.2.

• *RTNEPH.* The primary function of SFCTMP is to supply the RTNEPH with surface temperature data. These temperatures are required for RTNEPH's infrared threshold technique to determine the presence of cloud. SFCTMP, in turn, needs cloud information to properly determine the surface temperature. RTNEPH provides cloud amount, height (low, middle, or high), cloud type and clear sky infrared temperatures to the SFCTMP model. The role of clouds is discussed in more detail in Chapter 7. HIRAS uses satellite soundings and conventional data to produce 3-dimensional analyses of temperature, wind, and relative humidity. While its primary use is initializing the AFGWC Global Spectral Model (GSM), it supplies SFCTMP with low-level data.

• *SNODEP.* The Snow Analysis Model (SNODEP) contains the global location, depth, and age of snow cover. SNODEP uses surface observations, climatology, and a manual correction in producing its analysis. All snow information required by SFCTMP is obtained from SNODEP. The role of snow within SFCTMP is discussed in more detail in Chapter 7. More information on SNODEP, see Hall 1986.

• *AGRMET.* The agrometeorological model (AGRMET) is a Department of Agriculture model responsible for global analysis of agricultural variables. AGRMET supplies SFCTMP with the required soil moisture and evaporation variables. Information on AGRMET is available in Moore et al., 1991.

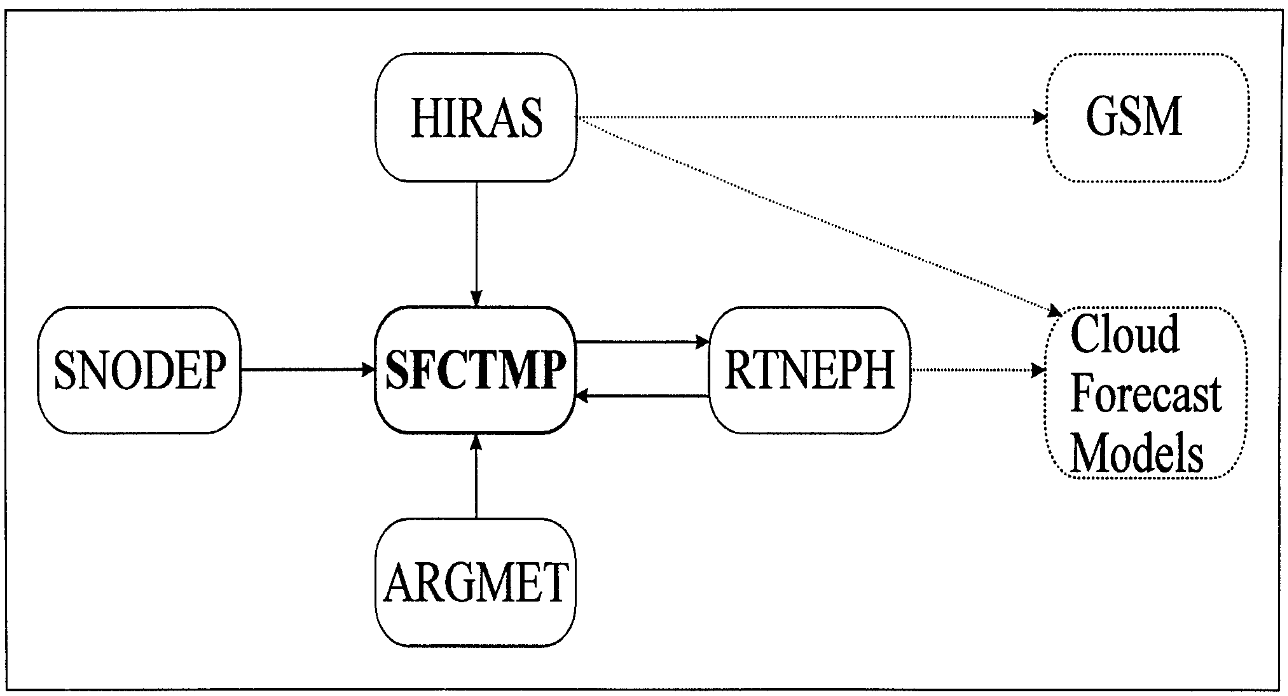

Figure 3-2. Key Model Interactions.

Chapter 4

HIRAS DATA PROCESSOR

4.1 General Description. The HIRAS Data Processor module retrieves HIRAS's low-level analysis of temperature, wind, relative humidity, and re-maps this 2.5 x 2.5 degree grid data onto the finer 1/8th-mesh polar stereographic grid for SFCTMP. This is done by using bilinear interpolation. Since HIRAS is only available every 6 hours (00, 06, 12, and 18 UTC), the wind and relative humidity fields are persisted for the "off" cycles 4 times (03, 09, 15, and 21 UTC). HIRAS temperatures during off-cycle times are not used, as other inputs are available (see Chapter 5). Further information on HIRAS is available in AWS/TN—86/001, *AFGWC's Advanced Weather Analysis and Prediction System (AWAPS).*

4.2 Supporting Data. In addition to the field variables mentioned above, this data processor uses the following supporting data:

• *Julian Hours.* Julian Hours are data resident in all databases. Previous cycle times and the expected current cycle time (for the appropriate database) are compared to actual current time to ensure only new data are retrieved for processing. All times are based on the AFGWC Julian calendar.

• *Geography and Terrain Heights.* The geography database defines each gridpoint as land, sea-ice, water, coast, or off-hemisphere. Sea-ice is treated as land during the analysis process.

The terrain data are actually 1/8th-mesh height difference values between the terrain heights on the coarse (2.5 degree) HIRAS grid and the 1/8-mesh SFCTMP grid. Terrain difference values are used during the adjustment process to correct temperatures assuming a 6 K/km lapse rate over the given height.

• *HIRAS Remap Coefficients.* Since the HIRAS grid is a mercator projection, its gridpoints do not match SFCTMP's polar stereographic grid. This database contains arrays of x- and y-coordinates of the HIRAS grid and corresponding half-mesh (100 nautical mile spacing) gridpoints of the polar stereographic grid.

Chapter 5

LAND ANALYSIS PROCESSOR

5.1 General Description. The SFCTMP Land Analysis Processor uses a two-step approach to create a shelter and skin temperature analysis over all non-water points. First, four different first-guess fields (HIRAS, 3-hour SFCTMP forecast, IR-derived, and SSM/I-derived surface temperatures) are blended using an optimum interpolation (OI) technique to create the first-guess shelter temperature field. Second, observed shelter height temperatures from conventional observations modify the first guess using a Cressman (1959) objective analysis scheme. Skin temperatures are produced after the shelter analysis is complete, as discussed in Section 5.4.

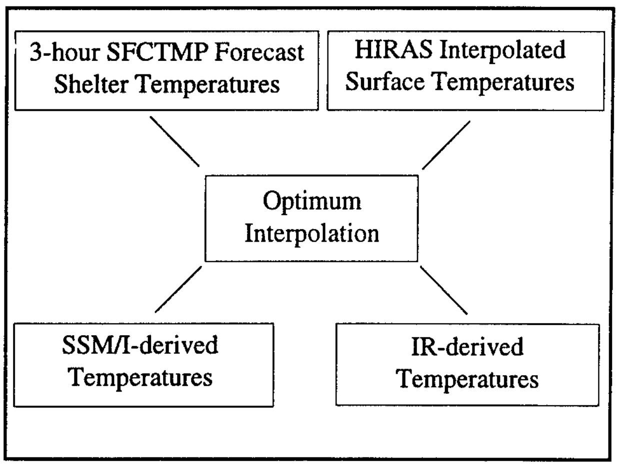

Figure 5.1 First-guess inputs for SFCTMP.

5.2 Optimum Interpolation. The Land Analysis Processor uses an OI technique based on Lorenc (1981). The four first-guess inputs utilized during the OI process are shown in Figure 5.1. Each input is dealt with in a similar manner. Error statistics are generated for each input by comparing their values to any timely conventional surface observations. Bias and root mean square errors (RMSE) are determined for each run and accumulated in the appropriate cycle (00, 03, etc.), sorted by RTNEPH box. These errors do not automatically cycle back into the OI process, but can be used to manually change statistics used in the OI, as discussed in Chapter 9.

Bias is calculated by accumulating the differences of the first-guess minus the observation. The formula is:

$$\text{BIAS} = (1/N\ \Sigma\Delta T) \qquad (5.1)$$

RMS error is calculated by the following formula:

$$\text{RMSE} = (1/N\ \Sigma\Delta T^2)^{1/2} \qquad (5.2)$$

where RMSE is the root mean square error, N is the number of observations and T is the difference between the observation and the first-guess shelter temperature for the appropriate input field.

The bias is then removed from the computation of the RMSE in order to remain consistent with the way input sources are used in the OI scheme. A final first-guess value is arrived at using the following algorithm at each non-water gridpoint :

$$FV^{ij} = W_1 DS_1^{ij} + W_2 DS_2^{ij} + W_3 DS_3^{ij} + W_4 DS_4^{ij} \qquad (5.3)$$

where FV^{ij} is the final first-guess value at point ij, W_x is the weight given to first-guess source x, and DS_x^{ij} is the grid point temperature according to first-guess source x at point ij.

The weight is related to the RMSE discussed above. The value of DS is modified by the bias. Characteristics of each of the four first-guess fields are discussed below.

5.2.1 ***HIRAS.*** HIRAS surface temperatures are available every 6 hours, at 00, 06, 12, and 18 UTC. The temperatures must be remapped from a 2.5 x 2.5 degree latitude/longitude grid to the SFCTMP 1/8th-mesh grid. This gives a deceiving picture of data resolution and quality, especially at lower latitudes. In addition, quality frequently suffers because HIRAS surface temperatures are vertically interpolated as well.

HIRAS has a small bias, ranging from +1°C to -1°C.

However, its RMSEs are generally poor compared to the RMSE of the previous 3-hour SFCTMP forecast, and may exceed 6° C on some cycles. Therefore, HIRAS is weighted less than the 3-hour SFCTMP forecast, but is similar to the IR-derived surface temperatures.

Thus, in regions where SFCTMP relies solely on HIRAS for new data input, model error characteristics are likely higher. These areas exist in any data sparse region, which hasn't been updated recently with IR or SSM/I -derived (RTNEPH) temperatures.

5.2.2 Previous 3-hour SFCTMP Forecast. Since SFCTMP runs every 3 hours, the 3-hour forecast from the previous cycle is used as a first-guess field. This forecast field produces the lowest bias and RMSE of shelter temperature and is therefore, the most reliable of the four first-guess input fields. In off-HIRAS cycles, the previous 3-hour forecast may be the only element in the first-guess field. As mentioned above, this occurs in data sparse regions where RTNEPH-temperatures have not been recently updated.

5.2.3 IR-Derived Temperatures. Whenever the RTNEPH determines a land or sea-ice location is cloud free, it stores the accompanying "clear-air" temperature for future use by SFCTMP. This clear-air temperature is actually a skin temperature modified by atmospheric attenuation. Since there is no worldwide method of verifying skin temperatures, IR clear-air temperatures are compared to shelter temperatures for bias and RMSE determination.

IR-derived temperatures rarely coincide with the model cycle times or the times conventional observations are taken. All available clear-air IR-derived temperatures are interpolated to the analysis time, instead of using an extremely limited number of IR-derived temperatures, or using them without consideration of the time factor.

The interpolation is a three-step process. First, SFCTMP produces a temperature coincident with the IR-derived temperature. Recall the previous SFCTMP run stored surface temperatures at the 0-, 3-, and 4.5-hour forecast times. Using the appropriate times and the IR-derived temperature time, SFCTMP interpolates a forecast temperature which matches the time of the IR-derived temperature. The difference between the interpolated SFCTMP forecast temperature and the IR-derived temperature is then applied to the previous 3-hour forecast. This value is used as the IR-derived temperature within SFCTMP.

Although IR bias and RMSE are stored by cycle time, the actual values vary more by satellite than by the cycle. The bias is almost always positive, and can be as large as 10°C. The RMSE also varies significantly, but is generally similar to HIRAS's.

5.2.4 SSM/I-Derived Temperatures. The method of evaluating SSM/I-derived surface temperatures is similar to the IR-derived temperatures. The SSM/I temperatures are produced within RTNEPH through a procedure described in the SSM/I Users Manual (Hughes Aircraft Company, 1992). SSM/I temperatures are compared to a time-interpolated SFCTMP temperature, the subsequent difference is applied to the SFCTMP 3-hour forecast.

Shortly after SFCTMP's implementation in 1991, the SSM/I derived surface temperatures became extremely unreliable and SSM/I data was removed from the first guess. SSM/I temperatures were not added to the first guess until January 1994 when more reliable surface temperatures were again available.

5.3 Objective Analysis. A Cressman analysis scheme is used to modify the first-guess analysis to smoothly fit the conventional observations. The scheme uses the sum of the weights squared, as recommended by Benjamin and Seaman (1985), in order to reduce the risk of discontinuities, especially over data sparse areas. The weight is also adjusted for height differences between the observation and the gridpoint, as discussed in DiMego (1988). The details of the procedure are given below.

The general objective analysis scheme uses the method of successive correction with a decreasing radius for

each iteration. SFCTMP goes through three iterations to reach its final analysis. The weight given to an observation for a given gridpoint is determined through the isotropic ciicular weighting function of:

$$W_{ij} = (R^2 - d_{ij}^2) / (R^2 + d_{ij}^2) \quad (5.4)$$

where Wij is the weighting function at grid point (ij), R is the Radius of Influence, and d_{ij} is the distance from the grid point to the observation.

The weighting function may be changed if the terrain height of the gridpoint and observation are dissimilar. In that case, the weighting function is altered by multiplying it by the factor:

$$[1 / (1 + (.0001 \bullet HDIF))]^2 \quad (5.5)$$

where HDIF is the height difference in meters.

The final analyzed shelter temperature (T_{ij}), at each gridpoint $_{ij}$ is given by:

$$T_{ij} = FV_{ij} + \Delta T_{ij} \quad (5.6)$$

where FVij is the first guess value from equation 5.2 and ΔTij is the observation-based correction given by:

$$\Delta Tij = \Sigma(W_{ij}^2 \bullet T_o) / \Sigma(Wij) \quad (5.7)$$

where T_o is the difference (observation minus first guess) at the location of the observation. The sum is over all observations within the radius of influence for the gridpoint.

Observations may be required to pass a "buddy check" before they are applied in the final analysis. Only observations significantly different than one of the first-guess field inputs undergo the check. If any one nearby observation ("buddy") is similar to the observation under consideration, the observation stays; otherwise, it's removed.

5.4 Determining Skin Temperatures. Once the final shelter temperature analysis is complete, the skin temperature can be determined. The skin temperature is produced by taking the difference between the previous 3-hour forecast of shelter and skin temperature, and applying that difference to the current shelter temperature analysis. Similar to the shelter temperature, skin temperatures are initialized over all land/sea-ice locations.

Note that the skin temperature analysis is dependent upon the shelter temperature analysis, not on the energy balance physics that drives the Land Analysis Processor. This leads to an infrequent occurrence referred to as a "shock effect" where the first time step in the forecast must restore the energy balance. This produces a radical change in the skin temperature. This effect is similar to a "spin-up" time in many numerical models. Future corrections to SFCTMP are anticipated to address this deficiency.

5.5 Databases. Besides the four databases providing the first-guess fields, this module also requires the Julian Hours and Geography/Terrain databases discussed in the previous chapter. Similar to the HIRAS data processor, the Julian Hours database ensures only timely data is used. The Terrain database heights are used in the Cressman scheme. Other supporting databases include:

• *Conventional Data.* This database contains worldwide surface observations. These observations are used for analysis and evaluation of the first-guess fields.

• *Tuning Coefficients.* These coefficients determine the bias and RMSE used in determining the first-guess. They also contain coefficients required for the Cressman scheme. This database is discussed in more detail in Chapter 9.

Chapter 6

SEA-SURFACE PROCESSOR

The Sea-Surface Processor is responsible for shelter and skin temperature analyses over all ice-free water points. Sea-ice is treated as land and is processed in the land analysis processor. Navy sea-surface temperatures (SSTs) are received once every 12 hours at AFGWC from the Fleet Numerical Meteorology and Oceanography Center over a whole mesh (2.5 degree) grid. The data is then remapped over the smaller grid used by SFCTMP.

A bilinear interpolation is used to remap the SSTs. Shelter and skin temperatures are assumed to be equal. Since SSTs change little over a 4.5-hour period, SSTs are held constant throughout the forecast period. Therefore, this processor produces the analysis and forecast for all water points.

SSTs undergo a data quality check each cycle. If any water point contains a temperature colder than 270 K or warmer than 310 K, all SSTs in that RTNEPH box are persisted from the previous cycle. This procedure not only prevents unrealistic SSTs, but also avoids an excessively noisy analysis.

Chapter 7

LAND FORECAST PROCESSOR

7.1 General Description. The Land Forecast Processor (TMPCST) is a vertically truncated version of the one-dimensional Oregon State University Planetary Boundary Layer (OSUPBL) model (Ek and Mahrt, 1989). The data inputs to this processor are shown in Figure 7-1. The model uses 30-minute time steps to produce 3- and 4.5-hour forecasts. Recall that simulated shelter temperatures are for a 2-meter height above ground level, and that the SST forecast is a persisted SST analysis.

The full OSUPBL model contains many atmospheric levels, but TMPCST uses only a single atmospheric surface layer. Because TMPCST has only one vertical gridpoint in the atmosphere (2-meter shelter height), the entire near surface vertical heat flux is parameterized in a top-of-the-model boundary condition. This is a necessary restriction due to computing power. The OSUPBL model also contains two soil layers (it can contain up to 10), both of which are used within TMPCST. Additionally, only a portion of the OSUPBL model soil hydrology physics are applied.

7.2 Model Physics. The OSUPBL model explicitly calculates a ground surface energy balance each time step, iterating heat fluxes and temperature changes over time. The surface energy balance is determined from the following equation:

$$(1-\alpha)S\downarrow + \downarrow L - \sigma T_{sk}^4 = G + H + LE + SNW \qquad (7.1)$$

where α is the surface albedo, $S\downarrow$ the downward solar radiation, $\downarrow L$ the downward longwave radiation, σT_{sk}^4 the blackbody longwave radiation emitted by the earth's surface (upward), G the ground heat flux (positive downward), H the sensible heat flux exchanged between the earth's surface and the atmosphere, LE the latent heat flux (surface evaporation), and SNW the heat flux from snow melt.

The primary objective of the model physics is to generate a new skin temperature. Computationally, the two downward radiation terms are solved first. The model then determines any latent heat exchanges and produces an intermediate "top layer soil temperature." This intermediate temperature allows for final computation of soil and sensible heat fluxes although the skin temperature has not yet been determined. The final step is determining the predicted skin temperature. With the skin temperature updated, the next time step is introduced, and a new shelter temperature is forecast. Details of the individual terms are discussed below.

7.2.1 Downward Solar Radiation Flux. The amount of downward solar radiation is determined through the equation:

$$S\downarrow = ((T_1 \bullet T_2 \bullet T_3 \bullet RTOP)/ D2) \qquad (7.2)$$

where T_1, T_2, and T_3 are transmissivity coefficients based on high, middle, and low cloud amount, respectively, RTOP is the value of solar radiation at the top of the atmosphere, and D2 is the double back scatter of incoming solar radiation from air and clouds.

The details of this method are given in AFGL/TR—82/0039. Shapiro's method is based on a three-layer plane-parallel atmosphere. Each of three possible cloud layers (high, middle, and low) transmits and reflects some of the solar radiation incident upon it. Each layer's transmissivity and reflectivity values depend upon the layer's cloud type and amount, as well as the solar zenith angle. The transmissivity and reflectivity values are empirically derived. Reflectivity values are included in the computation of D2.

The final total of downward solar radiation is multiplied by the factor $(1 - \alpha)$ where α is the albedo. Albedo values are available through climatological tables, except for snow and ice, which are set in the model itself. Current values are 0.5 for snow and 0.8 for ice.

7.2.2 Downward Longwave Radiation Flux. Downward longwave radiation is calculated by adjusting the blackbody longwave irradiance at the surface (σT_{sh}^4) with the vapor pressure and/or the presence of clouds. Initially, an "effective clear sky" emissivity is determined by an equation from Idso and Jackson (1969):

$$EF = .7 + (5.95e^{-5} \bullet E \bullet \exp(1500/T_{sh}) \quad (7.3)$$

where EF is the effective clear sky emissivity, E is the vapor pressure in millibars, and T_{sh} is the shelter temperature.

The total contribution of downward longwave radiation to the energy balance, including the effects of clouds, is computed from Wachtmann's model (Higgins et al., 1987). Wachtmann's model first uses EF to produce a modified clear sky emissivity according to:

$$ES = -.792 + (3.161 \bullet EF) - (1.573 \bullet EF^2) \quad (7.4)$$

ES is multiplied by the blackbody longwave irradiance (T_{sh}^4) to get the clear sky downward longwave radiation.

The contribution from clouds is considered through the following algorithm:

$$LC = (80 - (5 \bullet ZL)) \bullet FRACL \quad (7.5)$$

$$MC = (80 - (5 \bullet ZM) \bullet (1 - FRACL)) \bullet FRACM \quad (7.6)$$

$$HC = (80 - (5 \bullet ZH) \bullet (1 - FRACL) \bullet (1 - FRACM)) \bullet FRACH \quad (7.7)$$

where LC, MC, and HC represent the downward longwave radiation contribution from low, middle, and high clouds, respectively, ZL, ZM, and ZH are coefficients for low, middle, and high clouds respectively, and FRACL, FRACM, FRACH are the fractional cloud amounts of low, middle, and high clouds, respectively, as supplied by RTNEPH.

The three cloud terms and the clear sky term are added to obtain the final amount of downward longwave radiation:

$$\downarrow L = LC + MC + HC + (ES \bullet T_{sh}^4) \quad (7.8)$$

7.2.3 Upward Longwave Radiation Flux. The upward longwave radiation flux is the last term remaining in the energy balance, and is determined by Equation 7.1. The skin temperature is the last key parameter determined in each time step, using:

$$T_{sk} = [T_{adj} + ((ZZ1 - 1) \bullet T_{isoil})] / ZZ1 \quad (7.9)$$

where T_{sk} is the skin temperature, T_{adj} is the adjusted top layer soil temperature, ZZ1 is an adjusted soil flux, and T_{isoil} is the soil temperature of the first layer.

T_{adj} is required as an intermediate step in finding sensible and soil heat fluxes.

7.2.4 Soil Heat Fluxes. The soil heat flux on the upper boundary (skin/soil interface) is determined by the equation:

$$G = K_t(\theta) \bullet (\delta T/\delta x)_z = 0 \quad (7.10)$$

where G is the ground heat flux, $Kt(\theta)$ is the thermal conductivity of the soil (a function of soil water content), and $(\delta T/\delta x)z = 0$ is the thermal gradient at the skin/soil interface.

Soil temperatures are computed by the prognostic equation:

$$C(\theta) \bullet (\delta T_\chi/\delta t) = \delta/\delta z\,(Kt(\theta) \bullet (\delta T_\chi/\delta z)) \quad (7.11)$$

where $C(\theta)$ is the volumetric heat capacity, and T_χ is the temperature for the appropriate soil layer.

Note the gradient term now operates on the soil layer under consideration and the soil layer directly underneath. All other parameters are as before.

The above equations are still used under sea-ice conditions; however, the thermal conductivity of ice is used instead of the soil ($K_t(\theta)$). Soil depths are increased when ice is present.

Soil moisture is provided by the AGRMET model. The original OSUPBL model contains soil hydrology physics, but since soil moisture is available through an external source, the hydrology section was removed in SFCTMP to shorten processing time. Soil moisture is a constant when sea-ice is present.

7.2.5 Sensible Heat Flux. The sensible heat flux is a straightforward computation using:

$$H = \rho_o \bullet Cp \bullet Ch \bullet (\theta_{sk} - \theta_o) \qquad (7.12)$$

where H is the sensible heat flux, ρ_o is the air density, C_p is the specific heat of air, Ch is the exchange coefficient, θ_{sk} is the skin potential temperature, and θ_o is the shelter potential temperature.

7.2.6 Latent Heat Flux. Latent heat flux is divided into two parts, evaporation and snow melt. Determining actual evaporation begins with potential evaporation. A modified PENMAN technique (Mahrt and Ek, 1984) is used to calculate the potential evaporation. This involves computing an energy balance assuming a saturated surface state. The temperature determined from this calculation represents the temperature the skin would have if the soil was sufficiently wet to evaporate at the potential rate. Potential evaporation is derived from this idealized saturated surface state.

Once the potential evaporation is established, the actual evaporation is determined by multiplying the potential evaporation by the "beta" factor. The beta factor is commonly referred to as a "surface wetness factor" or "soil moisture availability," and simulates the role of vegetation in SFCTMP. The AGRMET model (Moore et al., 1991) provides the beta factor. Values of beta vary from 0 to 1. Default values are used for the RTNEPH boxes not processed by AGRMET, or when AGRMET's beta values are not realistic, producing unrealistic shelter temperature forecasts within SFCTMPs. The default values are empirically determined. Beta is assumed to be 1 over sea-ice and snow.

Snow cover and snow melt also affect latent heat fluxes. Snow cover and snow depth are available through the SNODEP model. Snow melt only occurs if the "provisional snow-ground surface temperature" is greater than 273.16 K (i.e., freezing). The provisional snow-ground surface temperature is based on an energy balance under the assumption of zero snow melt. If this temperature is less than or equal to 273.16 K, then it also becomes the new skin temperature. If greater than 273.16 K, the skin temperature is reset to 273.16 K and the excess heat is used as snow melt.

While snow melt is an integral part of the energy balance, snow depth plays a very small role. Snow depths remain constant in SFCTMP until updated by SNODEP.

Once the skin temperature is determined, the energy balance is completed. With the skin temperature updated, the next time step is introduced and a new shelter temperature is forecast.

7.3 Shelter Temperature Determination. The shelter temperature change is calculated using the following algorithm:

$$\Delta T = C_h \bullet C_{xx} \bullet \Delta t \bullet \Delta\theta \qquad (7.13)$$

where ΔT is the change in shelter temperature, C_h is the drag coefficient for heat, C_{xx} is the air heating coefficient, Δt is the time step (1800 seconds), and $\Delta\theta$ is the difference between shelter and skin potential temperature.

The magnitude of T is limited to the difference between the shelter and skin temperatures at the beginning of the time step.

The drag coefficient C_h is computed each time step at each gridpoint. The value of C_h depends upon whether the surface layer is stable or unstable; in other words, whether the virtual potential temperature of the shelter minus that of skin is positive or negative. The actual computation of C_h is quite complex. The reader is referred to Ek and Mahrt (1989) and subsequent references for further details.

The term C_{xx} has units of m^{-1}, and is supplied by a look-up table internal to SFCTMP (see Chapter 9). The values of C_{xx} are empirically derived. The use of an air heating coefficient (C_{xx}) allows SFCTMP to forecast air temperature changes with sufficient accuracy while eliminating the expense and complexity of modeling the planetary boundary layer. In the real atmosphere, shelter temperature changes are due to heat fluxes between the shelter and skin layers, and between the shelter and air layers above. This latter process is parameterized in SFCTMP through the parameter C_{xx}. C_{xx} is also discussed in Chapter 9.

7.4 Supporting Databases and Files. There are three supporting databases and numerous other files required to execute TMPCST. These three supporting databases are:

• *Geography/Terrain.* Only the geography database (land, water, coast, or ice) is necessary within TMPCST.

• *RTNEPH Database.* This database contains the cloud information (amount, layers) used by TMPCST.

• *SNODEP Database.* This database contains the snow depths required by TMPCST.

The files required by TMPCST are:

• *Albedo.* Climatological values for albedo are stored in four separate files for four months (January, April, July, October) for each land gridpoint. Albedos for the other months are interpolated within TMPCST. For snow or ice gridpoints, the albedo is set within TMPCST.

• *HIRAS.* Surface winds and surface relative humidities are taken from this file.

• *Roughness.* Surface roughness lengths for each land gridpoint are obtained from this file. These values are constant at each gridpoint.

• *Soil Temperatures.* Initial temperatures are required for each of the two soil layers available within TMPCST. These temperatures are based on the 3-hour forecast from the previous cycle.

• *Bottom Layer Soil Temperatures.* A constant bottom (third) soil layer temperature is needed at each land/ice gridpoint. This temperature is constant and assumed to be the gridpoint's average annual temperature. This temperature serves as a lower boundary condition in TMPCST.

• *Soil Moisture.* The amount of moisture within each soil layer is obtained from this file. The values are determined by the AGRMET model.

• *ETA and ETP.* These are initial values of actual (ETA) and potential (ETP) evaporation determined by the AGRMET model. They are stored only two times each day (00 UTC and 12 UTC). If needed at other times, ETA and ETP are interpolated from the 00 UTC and 12 UTC values. They are used to determine beta.

• *Temperature Analysis.* The initial shelter and skin temperatures produced by the Land and Sea-Surface Analysis Processors are passed to TMPCST through this file.

This large number of databases and files are necessary due to the requirements and complexity of the OSUPBL model.

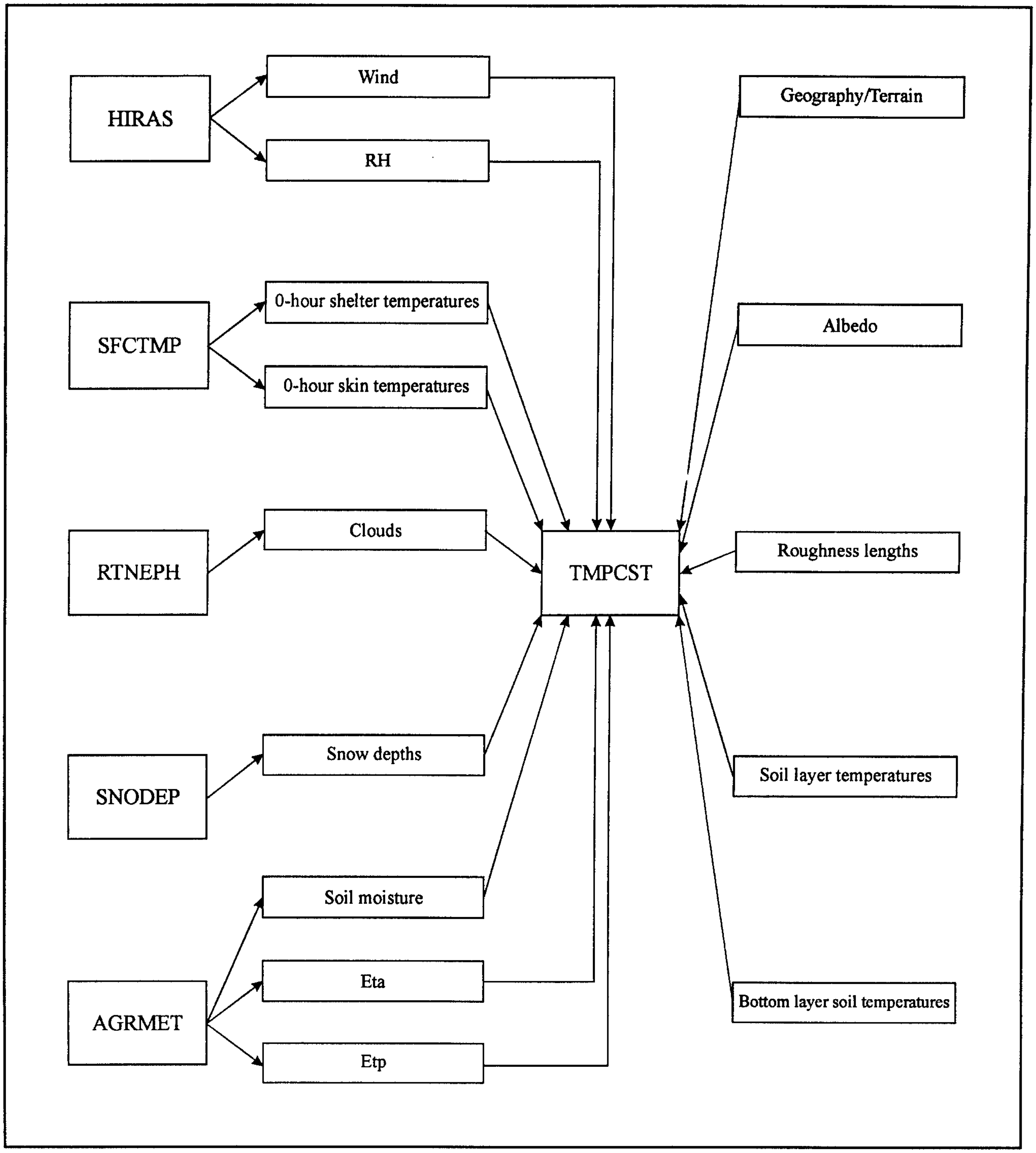

Figure 7-1. Data inputs to TMPCST.

Chapter 8

SMOOTHER

The final module in the program smooths the 0-hour analysis and the 3- and 4.5-hour forecast fields of shelter and skin temperature. The smoothing process is performed on a hemispheric grid, not on a RTNEPH box, to eliminate arbitrary box boundaries.

A 9-point smoother is applied. Only gridpoints over land and sea ice are considered. Points are excluded if they are over water, off-hemisphere, or if they differ significantly in elevation from the grid point under consideration. The structure of the smoothing process is that of a "boxcar" array with the weighting of the points as follows:

$$\begin{matrix} 1 & 2 & 1 \\ 2 & 4 & 2 \\ 1 & 2 & 1 \end{matrix}$$

Once the smoothing process is complete, SFCTMP is finished until the start of the next cycle.

Chapter 9

QUALITY CONTROL

9.1 Model Limitations. SFCTMP has a number of limitations. The most significant are listed below.

(1) The use of the RTNEPH creates several problems. Cloud cover does not change over the forecast period. Furthermore, the initial cloud cover is based on the most recent pass over the location by a satellite processed by the RTNEPH. It's possible for cloud cover over a gridpoint to be 4 hours old at initialization time, and more than 8 hours old by the time the 4.5-hour forecast is reached. Incorrect cloud cover can have a significant impact on SFCTMP output. Some common examples of these problems are given below:

• If the clouds reported in RTNEPH dissipate during daylight hours, SFCTMP may underforecast shelter temperatures due to insufficient solar radiation. Until RTNEPH reports clear skies, clouds will persist over a specified region.

• Likewise, if clouds dissipate over a location during nighttime hours, and RTNEPH reports cloud cover, SFCTMP may overforecast shelter temperatures due to excessive downward longwave radiation. Downward longwave radiation from clouds contributes to the energy balance. This can also result in an undesirable feedback between the models. SFCTMP would supply RTNEPH with an elevated shelter temperature value. Due to the threshold technique, RTNEPH will continue to analyze cloud cover even though it may not be present.

• If clouds develop over a location initially clear in RTNEPH during daylight hours, SFCTMP may overforecast shelter temperatures due to excessive solar radiation.

• If clouds develop over a location initially clear in RTNEPH during nighttime hours, SFCTMP may underforecast shelter temperatures due to excessive upward longwave radiation.

(2) SFCTMP's air temperature is unaffected by advection. The actual presence of cold (warm) advection can result in an over (under) forecast of shelter temperature.

(3) Snow cover is updated only once every 24 hours. Snow cover affects ground heat fluxes and snow melt, if the temperature is warm enough. If SNODEP reports snow cover, but in reality snow is not present, SFCTMP will underforecast shelter temperatures.

(4) Soil moisture and moisture availability (beta values) are updated once every 12 hours. The value of beta is difficult to determine, yet SFCTMP is sensitive to beta. AGRMET's beta values are often too low, but the default values, based on albedo, miss a significant amount of detail. Low beta values result in an overforecast of daytime shelter temperatures.

(5) Precipitation is not an input variable. Surface heat exchanges involved with precipitation do not exist within the model and the effect of precipitation on beta is ignored. The most significant effect on SFCTMP is the lack of evaporational cooling when precipitation occurs.

(6) Differences in soil texture are ignored. A mean value for the soil thermal coefficient is used for all land gridpoints. Soils with characteristics far from the mean may impact SFCTMP output.

(7) Roughness lengths are constant for all seasons. This also results in a loss of detail.

(8) Error statistics are generally not available over data sparse regions, making it difficult to assess the accuracy of the model in those locations. This problem is most evident in sea-ice and desert locations.

9.2 Accuracy. The accuracy of the model is evaluated for the 3-hour forecast of shelter temperature. The bias and RMSE are computed at each gridpoint where a suitable timely observation is available. The RMSE averaged over all gridpoints and cycles is currently less than 3.0 K. This compares with RMSE as high as 5.0 K in the previous surface temperature model.

Bias varies with forecast cycle and hemisphere, but is generally weakly positive. The summer hemisphere can contain a warm bias as high as 1.5 K for a given cycle, while the winter hemisphere can contain a cold bias as high as 1.0 K. These represent the worst case bias; however, the bias is near 0.5 K for most cycles.

9.3 Tuning SFCTMP. SFCTMP accesses a series of look-up tables. Other miscellaneous parameters are defined internally within SFCTMP. The name for the file containing these tables and parameters is TUNECO. The look-up tables have a significant effect on the analysis and forecasts produced by SFCTMP.

TUNECO contains adjustments for the four input variables (HIRAS, 3-hour SFCTMP forecast, IR- and SSM/I-derived temperatures) used in determining the first-guess shelter temperature. The bias and RMSE for each input variable is produced for each cycle and each RTNEPH box and is accumulated over time. As discussed in Chapter 5, these errors do not automatically adjust the input variables. Instead, the adjustments are located within TUNECO and must be *manually* altered if a change is detected in the bias or RMSE of any of the four inputs. Bias corrects a variable, while RMSE controls its weighting factor (see Section 5.2). This method allows changes in the quality of any of the four input variables to be immediately factored into the model.

Another important variable within TUNECO is the air heating coefficient (C_{xx}) mentioned in Chapter 7. C_{xx} significantly influences the diurnal heating and cooling within the forecast module. The values of C_{xx} are stratified according to the fraction of day/night and hemisphere (Figure 9–1). Errors are also computed for each fraction of the day and night; from these computations the air heating coefficient can be adjusted.

The only manual adjustments allowed within SFCTMP are through the TUNECO tables. No bogusing of SFCTMP input or output is possible, unlike other analysis programs at AFGWC such as the RTNEPH or the SNODEP.

Northern Hemisphere											
Fraction of day:	0	1	2	3	4	5	6	7	8	9	10
Day:	500	350	250	150	75	30	20	20	30	60	90
Night:	300	250	200	100	90	80	70	60	50	40	30
Southern Hemisphere											
Fraction of day:	0	1	2	3	4	5	6	7	8	9	10
Day:	500	350	190	90	40	20	15	15	30	60	90
Night:	250	175	150	100	90	85	80	75	70	65	60

Figure 9-1. Example of Cxx values (from December 1993).

9.4 Quality Control Procedures. Tuning SFCTMP depends significantly on the bias and RMSE statistics; yet, these statistics depend in turn on the presence of suitable, timely surface observations. Such observations are scarce or nonexistent in numerous areas. An alternative method of assessing SFCTMP analysis and forecasts on a global basis was needed.

The addition of a SUN workstation in 1991 allowed color displays of SFCTMP output on a hemispheric scale. The 0-, 3-, and 4.5-hour forecast results can be displayed for any cycle. The workstation software can loop the three images to observe the changes and to also "zoom" into an image for greater detail. Various color enhancements indicate warm or cold temperature anomalies. Figure 9-2 in an example of SFCTMP output as it appears on the workstation.

The ability to display SFCTMP output has proved invaluable in determining not only additional tuning requirements, but in identifying scientific or programmatic deficiencies in the model. Testing of subsequent corrections is aided by viewing the output of different versions of SFCTMP on the workstation. This assists greatly in maintaining the highest quality output from the SFCTMP model.

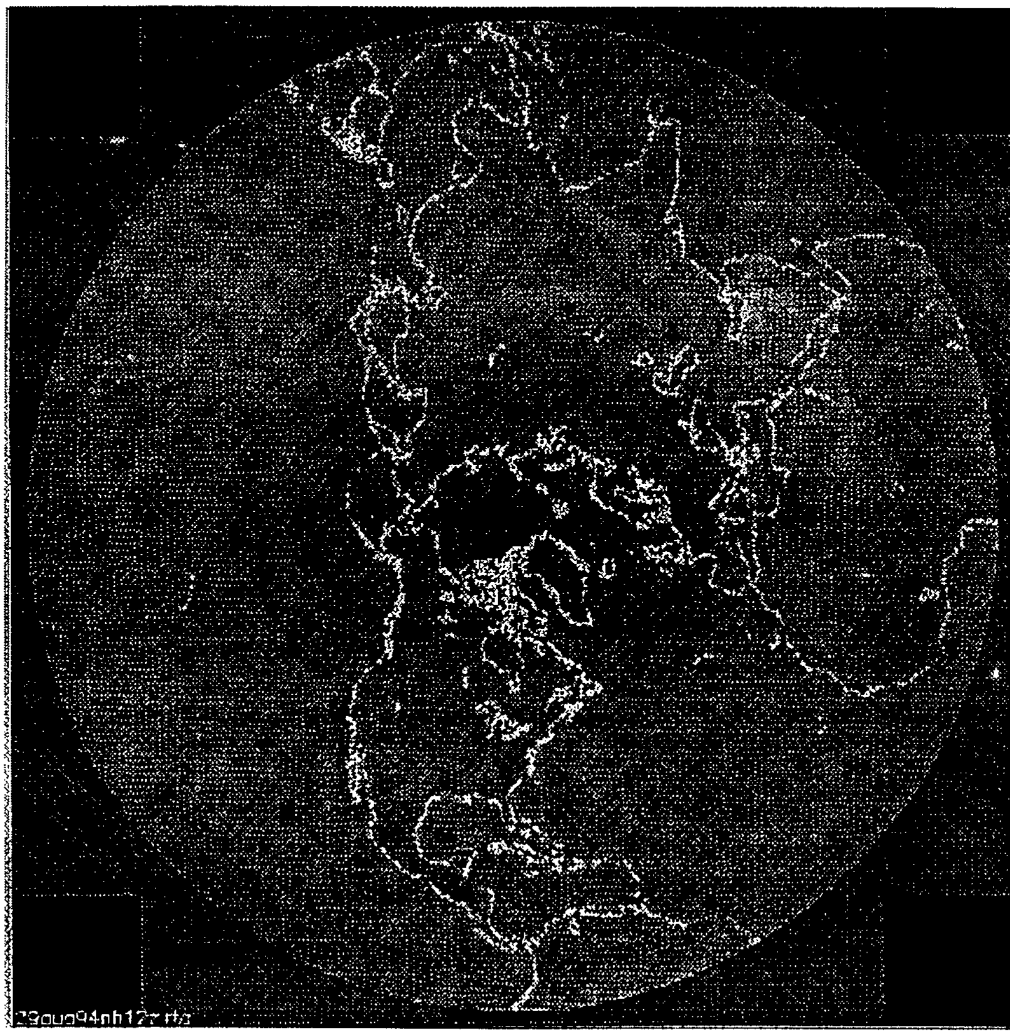

Figure 9-2. Example of SFCTMP on the workstation. Lighter shades indicate warmer temperatures. Example is from Aug. 29, 1994.

Chapter 10

CONCLUSION

The SFCTMP has analyzed forecast shelter temperatures since 1991. It provides the necessary background surface thermal field required by RTNEPH in order to produce quality global cloud analyses. SFCTMP provides a unique method of capturing global temperatures along with their diurnal variation on a timely basis in an operational environment.

ACRONYMS

AFGWC	Air Force Global Weather Central
AGRMET	Agrometeorological Model
ASPAM	Atmospheric Slant Path Analysis Model
DB	Data Base
FNMOC	Fleet Numerical Meteorology and Oceanography Center
GSM	Global Spectral Model
HRCP	High Resolution Cloud Prognosis
HIRAS	High Resolution Analysis System
IR	Infrared
OSUPBL	Oregon State University Planetary Boundary Layer Model
QC	Quality Control
RMSE	Root Mean Squared Error
RTNEPH	Real-Time Nephanalysis Model
RWM	Relocatable Window Model
SFCTMP	Surface Temperature Model
SSM/I	Special Sensor Microwave/Imager
SNODEP	Snow Analysis Model
SST	Sea-Surface Temperatures
TMPCST	Temperature Forecast Module
TUNECO	SFCTMP tuning parameters
WMO	World Meteorological Organization

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